Title of Grant / Cooperative Agreement:	Propellant-less Spacecraft Formation-Flying and Maneuvering with Photonic Laser Thrusters
Type of Report:	Summary of Research
Name of Principal Investigator:	Young K. Bae
Period Covered by Report:	10/01/13 - 09/30/15
Name and Address of recipient's institution:	Y.K. Bae Corporation, 218 W. Main St., Suite 102, Tustin, CA 92780
NASA Grant / Cooperative Agreement Number:	NNX13AR27G

Reference 14 CFR § 1260.28 Patent Rights *(abbreviated below)*
The Recipient shall include a list of any Subject Inventions required to be disclosed during the preceding year in the performance report, technical report, or renewal proposal. A complete list (or a negative statement) for the entire award period shall be included in the summary of research.

Subject inventions include any new process, machine, manufacture, or composition of matter, including software, and improvements to, or new applications of, existing processes, machines, manufactures, and compositions of matter, including software.

Have any Subject Inventions / New Technology Items resulted from work performed under this Grant / Cooperative Agreement?	No ◉	Yes ○
If yes a complete listing should be provided here: Details can be provided in the body of the Summary of Research report.		

Reference 14 CFR § 1260.27 Equipment and Other Property (abbreviated below)
A Final Inventory Report of Federally Owned Property, including equipment where title was taken by the Government, will be submitted by the Recipient no later than 60 days after the expiration date of the grant. Negative responses for Final Inventory Reports are required.

Is there any Federally Owned Property, either Government Furnished or Grantee Acquired, in the custody of the Recipient?	No ○	Yes ◉
If yes please attach a complete listing including information as set forth at § 1260.134(f)(1).		

Attach the Summary of Research text behind this cover sheet.

Reference 14 CFR § 1260.22 Technical publications and reports (December 2003)
Reports shall be in the English language, informal in nature, and ordinarily not exceed three pages (not counting bibliographies, abstracts, and lists of other media).

A Summary of Research (or Educational Activity Report in the case of Education Grants) is due within 90 days after the expiration date of the grant, regardless of whether or not support is continued under another grant. This report shall be a comprehensive summary of significant accomplishments during the duration of the grant.

ABSTRACT

The present NIAC Phase II program explored an amplified photon thruster, Photonic Laser Thruster (PLT), as a means of enabling unprecedented maneuverability of small spacecraft, such as cubesats, and reducing space system SWaP for future NASA missions and other commercial and DoD space endeavors. In addition to its propellantless operation capability, PLT can provide orders of magnitude more precise controls in thrust magnitude and vector than conventional thrusters. Furthermore, PLT promises to enable innovative CONOPS (Concept of Operations) to change how some NASA missions are conceived and to represent a revolutionary departure from the "all-in-one" single-spacecraft approach, where a primary factor that dominates spacecraft design is a heavy and risk-intolerant mission-critical payload. Instead, the PLT CONOPS has evolved from a different path based on interbody dynamics via thrust and power beaming. As interbody atomic dynamics unfolds completely new classes of molecular structures that cannot be formed by solo acting atoms alone, the PLT interbody dynamics is predicted to unfold unprecedented multibody spacecraft structures. Therefore, the revolutionary path of the PLT CONOPS represents a technology push rather than a mission pull, and will enable an entirely new generation of planetary, heliospheric, and Earth-centric missions. The chief accomplishments of the present Phase II program are: 1) achievement of photon thrust up to 3.5 mN (100 times scaling up of Phase I PLT) and amplification factor up to 1,500 (15 times enhancement of Phase I PLT), 2) laboratory demonstration of propelling, slowing and stopping a 1U cubesat on an air track with PLT, 3) proof of feasibility on persistent out-of-plane formation flying with PLT in simulation studies, 4) preliminary SolidWorks designs of 1-mN class PLT, 5) establishment of SWaP for flight-ready PLT, 6) designs for proof-of-concept missions of precision formation flying with cubesats, 7) definition of PLT-based NASA missions, such as Virtual Telescope. In sum, the present study conclusively demonstrated the potential of PLT to revolutionize future space endeavors by drastically enhancing maneuverability of spacecraft, reducing future space system SWaP by exploiting small spacecraft multi-system, and enabling innovative CONOPS.

The present NIAC Phase II program explored an amplified photon thruster, Photonic Laser Thruster (PLT), as a means of enabling unprecedented maneuverability of small spacecraft, such as cubesats, and reducing space system SWaP for future NASA missions and other commercial and DoD space endeavors. Since photons have extremely small momenta, thus thrust per power, the thrust amplification by recycling photons between two high reflectance mirrors located separately in two pairing satellites was proposed to amplify the photon thrust. During our previous investigation, we discovered that an active cavity, in which a gain medium is located within the optical cavity, is the solution to the desired photon thrust amplification that has been elusive over five decades [3-6]. Subsequently, we succeeded first time in demonstrating the amplified photon thruster and named such an active cavity photon thruster as Photonic Laser Thruster (PLT) as shown in Fig. 1.

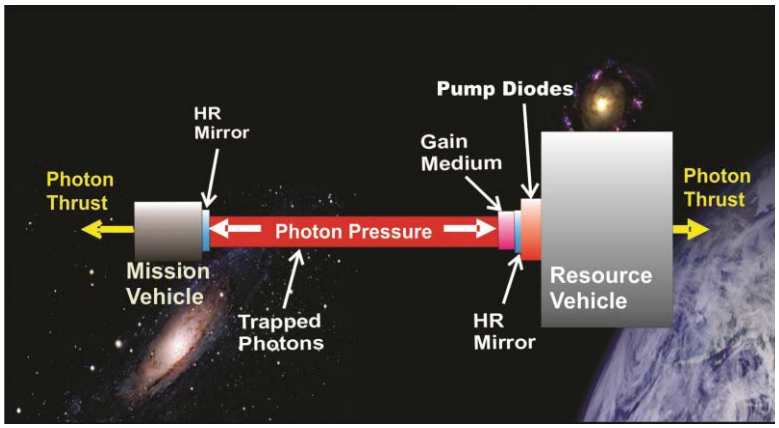

Figure 1. Schematic illustration of Photonic Laser Thruster (PLT) [3-6]. In addition to eliminating the need of fuels, PLT provides orders of magnitude more precise in control of thrust magnitude and vector than traditional thrusters. Thus, PLT enables the missions that are beyond the scope of the traditional thrusters.

Previsouly, we discovered that our photon thruster has a much broader scope in NASA mission applications [3-6]. In a systematic experiment, the optical cavity of PLT was demonstrated to be highly stable against tilting, vibration and motion of mirrors. This observation is in contrast with the characteristics of the traditional passive (no gain medium) optical cavity with high Q, which is highly unstable against any tilting, vibration and motion of mirrors. The reason for the observed stability for PLT is that in the active optical cavities for PLT the laser gain medium within the optical cavity dynamically adapts to the changes in the cavity parameters, such as mirror motion, vibration and tilting. The surprising discovery in our previous NIAC program on the extra stability of PLT opened the door to much wider NASA mission applications, such as precision formation without tethers and unprecedented spacecraft maneuvering without using any propellants [7].

Specifically, in addition to eliminating the need of propellants, PLT provides orders of magnitude more precise in control of thrust magnitude and vector than traditional thrusters. Therefore, PLT enables the missions that are beyond the scope of the traditional thrusters. The studies on these applications concluded that PLT can be also used for main propulsion, if its power and operational range are scalable, for propelling spacecraft to fraction of the light velocity and may enable even interstellar manned flight in far future [8,9].

Based on our theoretical calculation, we concluded that the large thin gain medium would be ideal for PLT as shown in Fig. 1. Fortunately, since our first PLT demonstration, the high power laser technology utilizing thin disk gain media, Thin Disk Laser (TDL), which is very similar to our original concept design of PLT, has rapidly evolved. Recently, an AFRL researcher for Directed Energy demonstrated intracavity laser power of 800 kW with a 6 kW TDL [10]. If such TDL is adapted for PLT, it would produce ~5 mN (more than 100 times scaling up of our previous demonstration of 35 μN) photon thrust. More recently, Boeing has announced that they have successfully demonstrated 30 kW power with their TDL [11]. If this TDL is adapted for PLT, the obtainable photon thrust would be at least 25 mN, which is about 700 times larger than the thrust in our first demonstration. With power and optics optimization, the photon thrust generated by PLT based on the TDL system technology is predicted to be considerably higher. It is one of the goals of this project to investigate the maximum attainable thrust in PLT based on such TDL system technologies and high power optics [10,11].

In this NIAC Phase II study, we have continued to explore the full potential of PLT for a wide range of NASA space missions. For example, PLT can provide persistent "out-of-plane" maneuvering capability that enables unprecedented persistent precision formation flying that is needed for NASA next-generation missions [7,12]. An illustration of such unprecedented formation flying configurations is shown in Fig. 2. In this structure, pushing-out photon thrust is counter balanced by differential gravity [7,12].

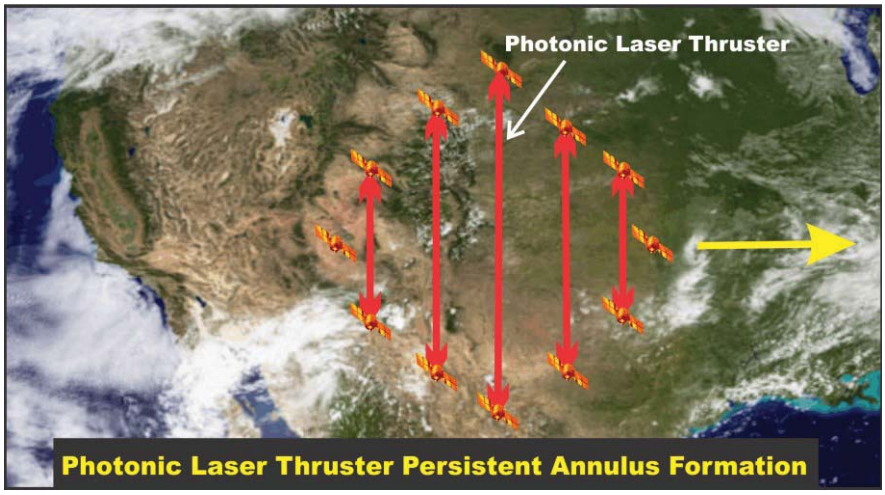

Figure 2. An artist's rendition of a persistent precision annulus formation with an aperture diameter exceeding 100 m in LEO with the use of PLT for persistent "orbit-normal" spacecraft maneuvering without expenditure of propellant.

More specifically, one of most crucial technologies to developing and implementing the PLT formation flying and spacecraft maneuvering is Directed Energy (DE) technology that has developed and matured long range delivery of how power laser beams [7,10,11]. The state-of-the-art DE technology is capable of delivering powers of multi-mega-watts over distances of hundreds of km in air, and matured precision pointing and focusing capabilities that are required for the large-scale PLT CONOPS. More recently, various solid state lasers are capable of delivering powers over 150 kW and are predicted to deliver multi-mega-watts powers in a decade. One of primary goals of the present program is to adapt state-of-the-art high power lasers developed for DE applications to dramatically expand applications for photon thrust in spacecraft propulsion for NASA missions [7]. Specifically, in this Phase II we have developed designed for space-qualified PLT and its flight demonstrations as a means of reducing future space system weight & size and enabling unprecedented maneuverability. In principle, PLT is capable of providing thrusts in the range of 1 mN – 1 N from an operational power source of 100 W – 100 kW delivered by currently available space-based solar panels. With such a PLT, sufficient thrust can be beamed from the resource vehicle to a mission vehicle with critical and expensive components without using propellant for propellant-less, ultra-precision spacecraft maneuvering, including station

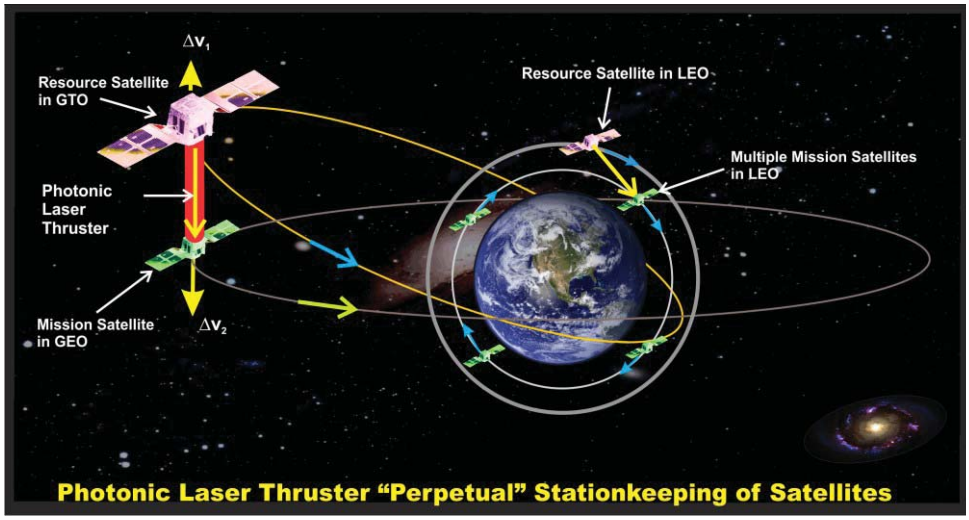

Figure 3. Examples of PLT stationkeeping. Left: A resource satellite orbiting in GTO beams momentum to a mission satellite in GEO for N/S stationkeeping. Right: A resource satellite orbiting in LEO beams momentum to multiple mission satellites in LEO for orbit drag compensation for station keeping.

keeping (see the Fig. 3), rendezvous and docking, orbit changing, and drag compensation. In such CONOPS, PLT can virtually eliminate fuel consumption and lower spacecraft life-cycle costs by orders of magnitude compared to traditional fuel systems [7,12,13].

In sum, if successfully implemented, the PLT CONOPS can:

- Enable missions that are beyond the scope of the conventional thrusters,
- Enable virtually unlimited mission lifetimes and expand operational capabilities, since advanced spacecraft maneuverings are no longer limited by onboard fuel,
- Lower construction/operation costs by reducing the hardware required for higher orbit applications,
- Eliminate environmental contamination or damage to mission crucial elements during proximate operations from cross firing of traditional thrusters.

Therefore, PLT promises to enable innovative CONOPS to change how some NASA missions are conceived, and is a revolutionary departure from the "all-in-one" single-spacecraft approach, where a primary factor that dominates spacecraft design is a heavy and risk-intolerant science payload. Instead, the PLT CONOPS is a low TRL concept that has evolved from a different evolutionary path based on interbody dynamics via thrust exchange. This revolutionary path that PLT CONOPS represents is a technology push rather than a mission pull, and will enable an entirely new generation of planetary, heliospheric, and Earth-centric missions. The PLT CONOPS is fundamentally beneficial to NASA, but there is relevance to other non-NASA applications that include chemical or radiation monitoring during descent through the upper atmosphere for intelligence purposes and ionospheric studies for ONR.

The chief accomplishments of the present Phase II program are:

1) achievement of photon thrust up to 3.5 mN and amplification factor up to 1,500,
2) laboratory demonstration of propelling, slowing and stopping a 1U cubesat on an air track with PLT as shown in Fig. 4,
3) proof of feasibility on persistent out-of-plane formation flying with PLT in simulation studies,
4) preliminary SolidWorks designs of flight-ready 1-mN class PLT,
5) establishment of SWaP for flight-ready PLT,
6) designs for proof-of-concept missions of precision formation flying with cubesats,
7) definition of PLT-based NASA missions, such as Virtual Telescope.

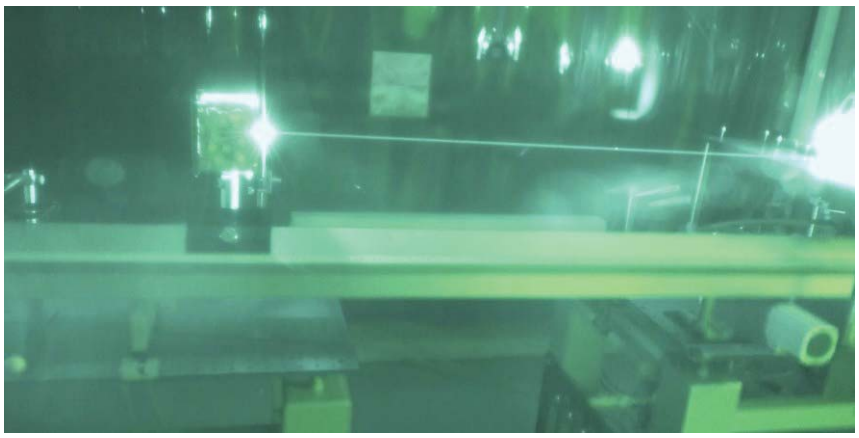

Figure 4. Demonstration of maneuvering a 1U Cubesat with Photonic Laser Thruster on an air track in laboratory environment.

In sum, the present study conclusively demonstrated the potential of PLT to revolutionize future space endeavors by drastically enhancing maneuverability of spacecraft, reducing future space system SWaP by exploiting small spacecraft multi-system, and enabling innovative CONOPS. The present achievements firmly established the technological foundation for a series of flight demonstrations that include pre-mission flight and actual mission demonstrations with PLT.

REFERENCES

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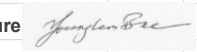
[12] Norman, M.C, and Peck, M.A., AIAA Conference Proceedings, 2009, 2009-6097.

[13] Peck, M.A. private communications, 2010.

Master Government Property List

Y. K. Bae Corporation

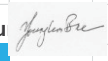
Property Manager: Young K. Bae **Signature**  **Date:10/02/2015**

Equipment List

Mfg Name	Noun Name Description Commercial Use	Mfg's Part Number	Model Number	Serial #	Gov. Asset ID #	Equip. ID #	Qty	WBS Project #	Unique-Item Identifier	Useful Life	Project Descriptor	Equpiment Location	Date Placed in Service	Condition	Status (Active, Stored, In-Transit or Waiting Disposal)	Property Type GFP/GFE/ GFM/CAP	Unit Cost (from Accounting System)
Thorlabs	Optical Cart system		POC001			G-1019	2	NNX13AR27G		5yrs		YKBC	11/18/2013	Working	Active	CAP	$4,313.62
Jefferson	Transformer		423-7161			G-1021	1	NNX13AR27G		5yrs		YKBC	12/1/2014	Working	Active	CAP	$1,147
Cleanroom West	Portable Cleanroom		VC-1000			G-1022	1	NNX13AR27G		5yrs		YKBC	12/2/2014	Working	Active	CAP	$14,438.72
Sartorious	Precision Balance	623-1S	ENTRIS			G-1023	1	NNX13AR27G		5yrs		YKBC	12/23/2014	Working	Active	CAP	$1,062.99
Airy	Cleanroom Particle Counter		P611			G-1024	1	NNX13AR27G		5yrs		YKBC	12/24/2014	Working	Active	CAP	$2,463.75
Coherent	Laser Power Meter		PM3K			G-1025	1	NNX13AR27G		5yrs		YKBC	12/30/2014	Working	Active	CAP	$4,507.57
Dausinger-Guissen	Thin Disk System		TDM 2.0			G-1026	1	NNX13AR27G		3 yrs		YKBC	12/31/2014	Working	Active	CAP	$179,383.83
Nilfist	Cleanroom Vacuum		GM80CR			G-1027	1	NNX13AR27G		5yrs		YKBC	12/31/2014	Working	Active	CAP	$1,171.70
PolyScience	Chiller for the laser system		DCA304S1-P			G-1028	1	NNX13AR27G		3 yrs		YKBC	1/20/2015	Working	Active	CAP	$8,556.91
Sony	Infrared Video Camera		FDR-AX33			G-1029	1	NNX13AR27G		3 yrs		YKBC	3/10/2015	Working	Active	CAP	$998.00

Master Government Property List (Materials)

Y. K. Bae Corporation

Property Manager: Young K. Bae **Signatu**  **Date:10/02/2015**

Contractor Acquired Materials

Mfg Name	Noun Name Description Commercial Use	Mfg's Part Number	Model Number	Serial #	Gov. Asset ID #	Equip. ID #	Qty	WBS Project #	Unique-Item Identifier	Useful Life	Pro Des	Equipme Locatior	Date Placed in Service	Condition	Status (Active, Sto or Waiting D	Proper GFP/G GFM/C	Unit Cost (from Accountin System)	Comments
Sciopt	Paraxia Designer	Suite	107-WIN-D		M-0098		1	NNX13AR27G		3yrs		YKBC	10/31/2014	Working	Active	CAP	$1,632.60	
Kentek	Laser Security Kit				M-0099		1	NNX13AR27G		3yrs		YKBC	11/13/2014	Working	Used	CAP	$3,726.00	Instal in cleanro/laser system
Thorlabs	Cleanroom cleaning	Kit			M-0100		1	NNX13AR27G		3ms		YKBC	12/2/2014		used	CAP	$177.45	
VWR	Cleanroom supplies				M-0101		1	NNX13AR27G		3ms		YKBC	12/4/2014		used	CAP	$1,307.70	
Absolute	Sticky Mat				M-0102		1	NNX13AR27G		3ms		YKBC	12/9/2014		used	CAP	$54	
Spectrum	Solvents				M-0103		1	NNX13AR27G		3ms		YKBC	12/12/2014		used	CAP	$317.25	
	Aceton						1B	NNX13AR27G							used			
	IPA						2B	NNX13AR27G							used			
Harkenrider	Cleanroom installa	Collections			M-0104		1	NNX13AR27G		3yrs		YKBC	12/22/2014		used	CAP	$1,344.90	installed into the cleanroom
Pasco	Air Track System				M-0105		1	NNX13AR27G		3 yrs		YKBC	1/5/2015		used	CAP	$1,692.72	installed into the exp system
McMaster	Plumbing Parts	SS Tubing	5364k233		M-0106		2	NNX13AR27G		3ms		YKBC	1/12/2015		used	CAP	$ 96.76	Total Tax=$90.37
		SS Tubing	9797t19		M-0107		6	NNX13AR27G		3ms		YKBC	1/12/2015		used	CAP	$ 358.56	S&H=$28.62
		SS Tube Fitting	52245k641		M-0108		4	NNX13AR27G		3ms		YKBC	1/12/2015		used	CAP	$ 433.08	
		SS tube Fitting s	52245k529		M-0109		2	NNX13AR27G		3ms		YKBC	1/12/2015		used	CAP	$ 128.84	
		SS tube Fitting s	52245k543		M-0110		2	NNX13AR27G		3ms		YKBC	1/12/2015		used	CAP	$ 112.40	
CVI	Laser Mirrors	HR Mirror	Y1-1025-0		M-0111		2	NNX13AR27G		2yrs		YKBC	1/12/2015		Active	CAP	$ 270.00	
SMC Pneu	Plumbing Parts	Fitting	KQ2S10		M-0112		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 43.70	Total Price $393.01- $2.00
		Fitting Elbow Ur	KQ2L10		M-0113		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 53.80	Tax+Shipping = $29.11
		Unifit Elbow Uni	KQ2L10		M-0114		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 46.10	
		Unifit	KQ2V10		M-0115		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 76.60	
		Plug Fitting	KQ2P		M-0116		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 12.00	
		Brass Inner slie	TJ-1065		M-0117		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 3.30	
		Fitting	KQ2S10		M-0118		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 41.10	
		Soft Tubing	TUS1065N		M-0119		1 pkg	NNX13AR27G		3ms		YKBC	1/23/2015		used	CAP	$ 87.30	
Instrumarts	Flow meter		7530-3-3-2-5c-08 + Option		M-0120		3	NNX13AR27G		2yrs		YKBC	1/23/2015		used	CAP	$ 735.00	Tax+S&S=$58.80

CVI	Laser Mirrors	HR Mirror	PR1-1030-99-1025	M-0121	2	NNX13AR27G	2yrs	YKBC	1/23/2015	Active	CAP	$ 640.00	S&H=$20
McMaster	Plumbing Parts	SS Tubing	52245k623	M-0122	2	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 156.46	Tax+$42.06
		Hose Fitting Ad	53505k76	M-0123	2	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 52.76	S&H=$8.31
		Hose Fitting Ad	53505k73	M-0124	2	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 48.44	
		Pipe fitting	5489k111	M-0125	2	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 6.26	
		PVC Sheet	8747k126	M-0126	2	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 34.56	
		tygon tubing	6534t35	M-0127	25ft	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 152.00	
		dry hose	5574k15	M-0128	1 pkg	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 9.97	
		dry hose	5574k14	M-0129	1 pkg	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 9.73	
		rectang bar	8740k73	M-0130	2 ft	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 24.06	
		flex tubing	9336t3	M-0131	25ft	NNX13AR27G	3ms	YKBC	1/26/2015	used	CAP	$ 31.50	
CVI	Laser Mirrors	HR Mirror	Y1S-1025-0	M-0132	4	NNX13AR27G	2yrs	YKBC	1/26/2015	Active	CAP	$ 660.00	
CVI	Laser Mirrors	HR Mirror	Y1S-1025-45	M-0133	4	NNX13AR27G	2yrs	YKBC	1/26/2015	Active	CAP	$ 660.00	
		HR Mirror	Y1-1025-05.00cc	M-0134	4	NNX13AR27G	2yrs	YKBC	1/26/2015	Active	CAP	$ 440.00	
Clean Air Produ	Cleanroom Cabinet			M-0135	1	NNX13AR27G	2yrs	YKBC	2/9/2015	Active	CAP	$2,679.00	**Tax=$214.32,SH=$712, Cr=**
	Grainger	SS Coupling	1LRY6	M-0136	1	NNX13AR27G	3ms	YKBC	2/11/2015	used	CAP	$ 5.75	Tax+S&H=$9.63
		Hose Barb	3DTT3	M-0137	3	NNX13AR27G	3ms	YKBC	2/11/2015	used	CAP	$ 75.45	
		SS Coupling	2UA51	M-0138	1	NNX13AR27G	3ms	YKBC	2/11/2015	used	CAP	$ 9.27	
		Hex Bushing	1LTE5	M-0139	2	NNX13AR27G	3ms	YKBC	2/11/2015	used	CAP	$ 11.00	
		Nipple	1XAC8	M-0140	1	NNX13AR27G	3ms	YKBC	2/11/2015	used	CAP	$ 5.61	
	Thorlabs	Laser Diode	S2011	M-0141	1	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 338.00	S&H=$61.72
		Long Fork	CF175C	M-0142	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 46.00	Tax=$288.92
		Al Breadboard	MB60-M	M-0143	1	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 483.00	
		Pillar Post	RS4P	M-0144	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 136.00	
		Pillar Ext	RS4	M-0145	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 104.00	
		Post Ext	RS2	M-0146	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 86.00	
		Post Ext	RS1	M-0147	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 74.00	
		Post Ext	RS6	M-0148	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 118.00	
		Laser Glasses	LG9	M-0149	4	NNX13AR27G	3ms	YKBC	2/13/2015	active	CAP	$ 784.00	
		clamp	SWC	M-0150	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 90.40	
		Post clamp	RA90	M-0151	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 39.04	
		Post clamp	RA45	M-0152	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 46.40	
		Mirror Mount	KS1	M-0153	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 335.20	
		Pelicle	BP150	M-0154	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 620.00	
		Pelicle Mount	KM100BP	M-0155	4	NNX13AR27G	3ms	YKBC	2/13/2015	used	CAP	$ 311.20	
	Thorlabs	Mirror Mount	KCB1	M-0156	3	NNX13AR27G	3ms	YKBC	2/23/2015	used	CAP	$ 419.82	S&H=$11.71
		Braket	CAM1	M-0157	3	NNX13AR27G	3ms	YKBC	2/23/2015	used	CAP	$ 290.40	Tax=$76.68
		Kin Mount	KM100-E03	M-0158	2	NNX13AR27G	3ms	YKBC	2/23/2015	used	CAP	$ 207.00	
		Adaptor	AS25E6M	M-0159	10	NNX13AR27G	3ms	YKBC	2/23/2015	used	CAP	$ 41.00	

McMaster	Plumbing Parts	Clear Tubing	50315k69	M-0160	1	NNX13AR27G	3ms	YKBC	2/27/2015	used	CAP	$	9.00	S&H=$5.42		
		Clear Tubing	50315k71	M-0161	1	NNX13AR27G	3ms	YKBC	2/27/2015	used	CAP	$	6.40	Tax=$14.62		
		Clear Tubing	50315k73	M-0162	1	NNX13AR27G	3ms	YKBC	2/27/2015	used	CAP	$	12.90			
		SS Hose Fitting	53505k77	M-0163	3	NNX13AR27G	3ms	YKBC	2/27/2015	used	CAP	$	106.02			
		SS Hose Fitting	53505k73	M-0164	2	NNX13AR27G	3ms	YKBC	2/27/2015	used	CAP	$	48.44			
McMaster	Plumbing Parts	Tube Fitting	5225k189	M-0165	1	NNX13AR27G	3ms	YKBC	3/3/2015	used	CAP	$	4.06	S&H=$4.81		
		Tube Fitting	5225k948	M-0166	1	NNX13AR27G	3ms	YKBC	3/3/2015	used	CAP	$	6.98	Tax=$2.62		
		Tube Fitting	5225k187	M-0167	1	NNX13AR27G	3ms	YKBC	3/3/2015	used	CAP	$	5.95			
		Tube Fitting	5225k193	M-0168	1	NNX13AR27G	3ms	YKBC	3/3/2015	used	CAP	$	8.55			
		hose clamp	5321k14	M-0169	1 pg	NNX13AR27G	3ms	YKBC	3/3/2015	used	CAP	$	7.20			
McMaster	Plumbing Parts	filter	4448k46	M-0170	1	NNX13AR27G	3ms	YKBC	3/5/2015	used	CAP	$	97.72	S&H=$6.95		
		Mount Bracket	44195k4	M-0171	1	NNX13AR27G	3ms	YKBC	3/5/2015	used	CAP	$	8.14	Tax=$12.76		
		Hose adaptor	70705t63	M-0172	1pkg	NNX13AR27G	3ms	YKBC	3/5/2015	used	CAP	$	9.29			
		Poly Tube Reinf	51165k13	M-0173	1	NNX13AR27G	3ms	YKBC	3/5/2015	used	CAP	$	7.56			
		cl cartridge	4448k47	M-0174	1	NNX13AR27G	3ms	YKBC	3/5/2015	used	CAP	$	36.88			
Western State S	Cleanroom Table		EA-t2436seb	M-0175	1	NNX13AR27G	3yrs	YKBC	3/6/2015	active	CAP	$	667.00	S&H=$85, Tax=$36.31		
CVI	Laser Mirrors	HR Mirror	Y1-1025-0-3.00cc	M-0176	2	NNX13AR27G	2yrs	YKBC	3/11/2015	Active	CAP	$	440.00			
Coast Pneumatic	Plumbing Parts	Air Filter	AFD40-N04D-Z	M-0177	1	NNX13AR27G	3ms	YKBC	3/12/2015	used	CAP	$	83.60	S&H=15.95, Tax=$8.71		
		Fitting	KQ2P-10	M-0178	1 pkg	NNX13AR27G	3ms	YKBC	3/12/2015	used	CAP	$	17.90			
		Fitting	TJ-1065	M-0179	2 pkg	NNX13AR27G	3ms	YKBC	3/12/2015	used	CAP	$	7.40			
McMaster	Plumbing Parts	tube fitting	5225k189	M-0180	2	NNX13AR27G	3ms	YKBC	3/16/2015	used	CAP	$	8.12	S&H=$5.60		
		tube fitting	5225k186	M-0181	4	NNX13AR27G	3ms	YKBC	3/16/2015	used	CAP	$	13.80	Tax=$5.79		
		tube fitting	5225k199	M-0182	4	NNX13AR27G	3ms	YKBC	3/16/2015	used	CAP	$	22.32			
		poly tubing	50315k71	M-0183	1	NNX13AR27G	3ms	YKBC	3/16/2015	used	CAP	$	16.00			
		air filter	3881t51	M-0184	1	NNX13AR27G	3ms	YKBC	3/16/2015	used	CAP	$	12.17			
HomeDepot		Torque wrench		M-0185	1	NNX13AR27G	3ms	YKBC	3/20/2015	used	CAP	$	59.97	Tax=$9.59		
		Hex Drive		M-0186								$	19.97			
		Digital Level		M-0187								$	39.99			
Coast Pneumatic	Plumbing Parts		Miscellaneous fittings	M-0188	1	NNX13AR27G	3ms	YKBC	3/25/2015	used	CAP	$	59.40	Detailed Receipt Missing		
B&H Camera	Camara Equip	Tripod	VT-4000	M-0189	1	NNX13AR27G	3yrs	YKBC	3/30/2015	acitve	CAP	$	218.50			
		Momory Card	Sandisk 128Gb	M-0190	1	NNX13AR27G	3yrs	YKBC	3/30/2015	acitve	CAP	$	147.95			

American Clean Stat			Cleanroom Frock		M-0191		1	NNX13AR27G	3 ms		YKBC	3/31/2015		used	CAP	$ 332.06	Tax=$26.56
VTE	Cleanroom Air Gun Assembly		VT 208		M-0192		1	NNX13AR27G	3yrs		YKBC	3/31/2015		acitve	CAP	$ 206.79	Tax=$16.54, SH=$10.88
McMaster	Al Disk	disks	7775t31		M-0193		2	NNX13AR27G	3ms		YKBC	4/6/2015		used	CAP	$ 104.14	
Image One Cam		Cam Filter	Dot-1268		M-0194		1	NNX13AR27G	3yrs		YKBC	4/6/2015		acitve	CAP	$ 79.96	Tax=$12.79
		Camera Bag	TMC-0069		M-0195		1	NNX13AR27G	3yrs		YKBC	4/6/2015		acitve	CAP	$ 79.95	
McMaster	Al Disk	disks	7775t31 3/4 inch		M-0196		1	NNX13AR27G	3ms		YKBC	8/11/2015		used	CAP	$ 48.68	Tax=$7.69
		disks	7775t31 0.5 inch		M-0197		1	NNX13AR27G	3ms		YKBC	8/11/2015		used	CAP	$ 47.54	SH=$5.26
Pumpkin Inc	1U cubesat	Cover Assemb	710-00296		M-0198		1	NNX13AR27G	3yrs		YKBC	8/24/2015		active	CAP	$ 375.00	SH=$20
		Wall Chasis	703-00289		M-0199		1	NNX13AR27G	3yrs		YKBC	8/24/2015		active	CAP	$ 925.00	Tax=$146
		Base Plate Ass	710-00794		M-0200		1	NNX13AR27G	3yrs		YKBC	8/24/2015		active	CAP	$ 525.00	
Newport Optics	Super Mirror		10c700sr.50f		M-0201		2	NNX13AR27G	3yrs		YKBC	9/21/2015		active	CAP	$1,998.00	Tax=$159.84